THE RESPONSE OF WHEAT GROWN IN CALCAREOUS SOILS TO IRON FERTILIZERS

BY

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INTRODUCTION

Calcareous soils are estimated to cover about one third of the total land surface of the earth (Wallace and Lunt, 1960). Most of the soils in Jordan, especially in the Jordan Valley, are highly calcareous. The surface layer of most of the soils in the Jordan Valley contains more than 35% $CaCO_3$ and might reach over 65% in some cases[#]. The alkaline reaction of these soils decreases the availability of micronutrients especially iron. Added iron tends to become insoluble and unavailable to plants in these soils. Although total iron in soils ranges from 1 to 10% and is rarely less than 1%, its insolubility ranks it with the micronutrients. Iron deficiency in alkaline soils leads to an abnormality known as lime-induced chlorosis.

Observations on crops grown in the Jordan Valley, especially citrus fruit trees, show symptoms of possible deficiency of iron and other micronutrients. Little work has been carried out by The Department of Agricultural Research and Extension to identify the problem for future

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[#] Rawajfih, Z. and D. Daoud (unpublished data).

remedies. Three soils representing the major portion of the cultivated area in the Jordan Valley were chosen in the present investigation and a greenhouse experiment was set up with the following objectives.

1- To check the adequacy of the indigenous iron in these highly calcareous soils for wheat growth.

2- To measure the effect of added inorganic and chelated iron on the dry matter yield of wheat.

3- To evaluate the added Fe fertilizers on the iron concentration in the plant as well as on the total iron uptake.

4- To study the effect of added inorganic or chelated iron on extractable iron as an index for its availability to plants.

LITERATURE REVIEW

The soils of the Jordan Valley are highly calcareous. Their calcium carbonate content in the surface layers is usually more than 35% and is rarely below 20%.# Iron chlorosis in calcareous soils is not necessarily related to the amount of $CaCO_3$ in the soil. For example, Gile and Carrero (1920) found that 2% of carbonate of lime was sufficient to affect some plants growth in some soils, where in other soils 76.7% $CaCO_3$ did not induce iron chlorosis.

Iron in Soil

Iron content in soils ranges from 1 to 10% and soils rarley contain less than 1% Fe (FAO,1972). It is present mainly as oxides, sulfates, sulfides, carbonates, and silicates. The total amount of Fe in soils is generally a very poor indicator of its availability to plants.

Rawajfih, Z and D. Daoud (unpublished data) .

The effect of carbonates on the availability of iron to plants

Calcium carbonate in the soil reduces the availability of iron. Seatz and Peterson (1965) reported that reactions between carbonate ions and iron may be a factor in reducing iron availability to plants; they cited the following exo - thermic reactions

$$Fe^{2+} + CaCO_3 \rightleftharpoons FeCO_3 + Ca^{2+}$$

$$4\,FeCO_3 + O_2 + Ca(HCO_3)_2 \rightleftharpoons 2\,Fe_2(CO_3)_3 + Ca(OH)_2$$

$$Fe_2(CO_3)_3 + 3H2O \rightleftharpoons Fe_2O_3 + 3\,H_2CO_3$$

In addition to the precipitation of iron as insoluble forms in calcareous soils, the high buffering of $CaCO_3$ or HCO_3^- ion in these soils minimizes the possibility of the plant roots developing localized areas of improved iron nutrition (Champman, 1939)[#] .

The presence of bicarbonate in soil or in the irrigation water induces iron chlorosis. It is possible that HCO_3^- interfers somehow with the active transport of iron and does not exert an effect unless it is present at the sites where iron is being accumulated (Brown et al., 1959[##]).

The level of calcium in solution also affects iron availability. Brown (1961) reported that increasing the concentration of calcium in nutrient solution decreased the

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[#] From Lindner and Harley (1944).

[##] From Wallace and Lunt (1960).

absorption of iron by plants.

Ferric iron in solution varies with pH; it decreases 1000 fold when raising PH by one unit and reaches a minimum in the pH range of 6.5 to 8. Above pH 8, $Fe(OH)_4^-$ is the major ion in solution. The activity of Fe^{2+} decreases 100 fold with each unit increase in pH and at pH values greater than five the ferrous ion concentration is less than 0.01 ppm (Lindsay, 1972). In aqueous solutions Fe^{2+} is oxidized to Fe^{3+} in the presence of oxygen. This oxidation occurs rapidly in near neutral and alkaline solutions (Wallace and Lunt, 1960). Lack of O_2 hinders or stops the uptake of most nutrients. However, the roots of cereals have been observed to excrete acids and other compounds under anaerobic conditions and these exudates may have an oxidizing or reducing action (Grable , 1966).

The availabilty of iron in calcareous soils appears to be slightly greater near the optimum water content of the soil than at higher percentages of water (Gile and Carrero, 1920).

The effect of other nutrients on the availability of iron

The availability of iron to plants does not depend only on its amount in the growing medium. A balance between iron and certain nutrients must be maintained so that plants can obtain the needed amount of iron.

Phosphorus concentration in the growth media is important in iron nutrition. In a Hogland solution containing 2.2 mM ferrous sulfate-tartrate and 0.0,0.1, 1.0 or 2.5 mM phosphorus,Ajakaiye (1979) found that the higher P concentrations inhibited ^{55}Fe absorption and translocation in sorghum plants and the best level of P for sorghum growth was 0.1 mM; iron concentration in plant declined as P level increased. On the other hand, Watanabe et al . (1965) found that the Fe concentration in corn did not change with increasing P in the nutrient solution (pH 7.5), but P/Fe ratio in the plant increased over three fold. They also found that with an adequate supply of Fe, phosphorus did not casue Fe to be deficient even though the Fe content of the tissue did not increase. Estes and Bruetsch (1973) found that 4.8 ppm Fe produced excellent plant growth when P levels were less than 22ppm in the nutrient solution. Their field studies showed significant reduction of tissue Fe at a phosphorus fertilization level of 50 kg P/ha as superphosphate compared to the control. In trying to explain the effect of P on the availability of Fe, Olsen (1935)[##] concluded that iron is precipitated as iron phosphate in the leaf tissue.

Most reports in the literature indicate a clear-cut antagonism between Fe and Mn which can influence the

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[#] From Lindner and Harley (1944)

mineral composition of the plant to a very considerable extent. Evidence has been presented to show that the Fe/Mn ratio affects the growth and the condition of the plant more than the absolute concentrations of these nutrients (FAO, 1972 ; Hewitt, 1948). Vlamis and Williams (1964) found that the Fe content of barley plants decreased with increasing Mn in the nutrient solution.

Among other nutrients that affect the availability of iron is zinc. Lingle et al . (1963) found that Zn depressed Fe uptake and also interfered with the translocation of Fe to the tops of soybean. Watanabe et al . (1965) concluded that the increase of Zn in the corn plant upset the normal metabolic function of Fe and caused depression in yield. In a pot experiment with wheat grown in silty clay loam soil of pH 7.8, Sakal and Singh (1977) found that the incorporation of $CaCO_3$ and Zn significantly reduced the shoot weight from 37.02 to 32.14 g/ pot and decreased the Fe and Mn content of different parts of wheat plants.

Many other factors which could affect the availability of iron directly or indirectly have been reported. These include molybdenum level in the soil, temperature, light intensities, high levels of nitrate nitrogen, the addition of certain organic compounds to the soil, viruses, and root damage by nematodes or other organisms (Russell, 1973; Wallace and Lunt, 1960; Brown, 1961).

Soil extractable iron

Several methods for estimating the level of available Fe in soil have been proposed. Micronutrient soil tests generally attempt to measure one or several forms of the micronutrient in the soil that can be related to the nutrient availability for plants. The amounts of readily soluble Fe in soils obtained with different extraction techniques are hardly comparable .

The ammonium acetate (1N at pH 4.8) method is better fit for acid soils and cannot be used for calcareous soils. When using this method, 2 ppm or more of extractable Fe means there is sufficient Fe for growth (Olson, 1965). Paddich (1948) suggested the use of thioglycolic acid to test for the availability of Fe in alkaline soils.

Johnson and Young (1973) recommended the use of 0.001 M ethylenediamine di (o-hydroxy phenyl acetate) EDDHA in 0.1 M $NaNO_3$ for extracting iron from calcareous soils and as an analytical reagent. They found that solutions of FeEDDHA followed Beer's law over the pH range 3.0-9.0 and were not affected greatly by foreign metals. Free calcium carbonate did not affect either the extracting or analytical properties of the reagent.

The most promising method applicable to calcareous and alkaline soils appears to be the diethylenetriamine - pentaacetic acid(DTPA)extraction method developed in the United States by Lindsay and Norvell (1969) and reevaluated by the same workers later (Lindsay and Norvell, 1978). The extractant consists of 0.005 M DTPA, 0.1 M triethanol amine (TEA) and 0.01 M $CaCl_2$. The extractant is buffered at pH 7.3 and contains $CaCl_2$ so that equilibrium with $CaCO_3$ is established at a CO_2 level about 10 times that of the atmosphere. Thus the extractant precludes dissolution of $CaCO_3$ and relase of occluded nutrients which are normally not available to plants. For 35 calcareous soils a critical level of 4.5 ppm DTPA extractable Fe separated the responsive from the nonresponsive soils in the greenhouse using sorghum (Lindsay and Norvell, 1978). Many investigators tested the usefulness of DTPA as an extractant for available Fe. deBoer and Reisenauer[#] (1973) found that the method successfully predicted deficiency of field grown sorghum with a critical level of 6 ppm of extractable Fe. They also found that sorghum response in the greenhouse was successfully predicted with a critical level of 5 ppm of extractable Fe . But Rule and Graham (1976) found that soil labile pools of Fe were in disagreement with DTPA-measured pools.

[#] From Lindsay and Norvell, (1978) .

Iron in Plant

Brown (1961) reported that Sachs (1860) is credited as being the first to establish that iron is an essential element for the growth of higher plants. The Fe content of normal plant tissues ranges from around 25 to more than 500 ppm (FAO. 1972). Ermolenko (1966) reported the values 42 and 58 ppm in winter and spring wheat respectively.

The role of iron in plants

Iron plays a big role in plants as an enzyme activator during specific biological reactions. Examples are fumarate hydrogenase, catalase, peroxidase, cytochrome, and DPNH-Cytochrome C reductase. Protohaematin (which forms part of peroxidase, Catalase, and cytochrome b group) is the main form of iron compounds in nongreen parts of plants (Ermolenko, 1966). It has been found that only about 0.1% of the iron in the plant leaves is involved in the heampigments (Dekock, 1971).

Iron uptake from soil

It is not known definitely whether plant roots take up their iron as the ferrous or ferric ion, nor whether they take it as an iron ion or as an organic coordination (Russell, 1973). Wallace and Shannon# (1956) reported that

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From Wallace (1963)

24% of the iron removed by plants from a calcareous soil was in the anion form which supposedly was associated with chelating agents occurring naturally in the soil. It has been suggested that plant roots secrete free organic acids and enzymes in the soil and then reabsorb them together with a given trace element bound as chelate (Ermolenko, 1966). When iron is applied as a chelate it may be absorbed as Fe or as a chelate complex. Jeffreys et al . (1961) found that when $^{59}Fe^{14}C$EDDHA was fed to bushbeans at pH 7, the concentration of ^{59}Fe and ^{14}C in the plant were equal while at pH 8.5 the concentration of ^{14}C exceeded that of ^{59}Fe . It was reported that EDDHA was absorbed and distributed within soybean plants and that Fe also stimulated the translocation of EDDHA from roots to leaves (Wallace and Hale, 1961). Brown (1969) reported that Fe-deficient plants did not take up iron and the chelating agent in equivalent quantities, but preferentially took up iron from a solution of iron chelate. Nonchlorotic plants did not show this pronounced differential uptake and they took up less iron than chlorotic plants.

There does not seem to be an agreement on the mechanism through which Fe is supplied to plant roots. While O'Conner (1973) reported that diffusion is the most important mechanism for supplying iron to plant, El-Khattari (1977) found that the main mechanism of Fe uptake by sorghum plants from Fe fertilizers, especially from inorganic sources, seemed to be by direct root contact.

Iron can be considered to be at least moderately mobile in plant (Deckock, 1971) with iron citrate being the major compound responsible for this mobility (Tiffin, 1972). Brown and Tiffin (1965) found that movement of iron was associated with citric acid under deficiency condition. The transport of iron within the plant has been observed to be affected by the pH of the conducting tissue with pH gradients resulting in iron accumulation; iron accumulation was absent in plants with low pH throughout their tissues (Rogers and Shive[#], 1932).

Iron deficiency

Botanists sometimes group plants into two major categories; the calcicole plants that are fairly tolerant to calcreous soils and the calcifuge plants that prefer acid soils and are rarely found on calcareous soils. Calcifuges growing on neutral or calcareous soils typically show symptoms of a trouble known as lime-induced chlorosis which is due to an upset in the iron nutrition of the plant (Gile and Carrero, 1920; Russell, 1973). Small[# #] (1946) when reviewing older reports, observed that increasing the pH of nutrient solutions generally resulted in more total Fe and less soluble Fe in leaves. Iron was found precipitated in tissues of relatively high pH (5.6-6.2) in a number of species and even in oxalis stems

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[#] From Brown (1961)

[##] From Wallace and Lunt (1960)

where pH does not exceed 4.4 . He suggested that acid-loving plants might have a dominant oxalate-malate buffer system and that such plants are injured by alkalization of the external root medium. He believed this to be the essential characteristic of the calcifuge plants. In contrast, species with a citrate-phosphate buffer complex are believed to be more adapted to high pH conditions while a balanced citrate-malate- phosphate system leads to a wider range of adaptability. These principles might explain lime-induced chlorosis as well as why some species do better at high pH. Ermolenko (1966) stated that some plant species, especially cereals, are capable of regulating the supply of trace elements from outside so well that no trace elements in excess accumulate inside the plant. Such plants are less sensitive to excess trace elements concentrations.

Iron deficiency is in fact the first nutrient deficiency in plant ever to be reported. A general chlorosis of the young leaves is the most telling symptom of iron deficiency . At first the veins may remain green, but in most species in which deficiency has been observed the veins also become chlorotic eventually (Epstein, 1972).

Bennett (1945) concluded that total iron is distributed between the active and residual fractions of protein and this distribution varies between chlorotic and green leaves where green leaves contain more active iron. He also reported that tissue suspensions contained both Fe^{2+} and Fe^{3+}

in an easily displayed equilibrium. The distribution of iron between Fe^{2+} and Fe^{3+} in living cells may be expected to vary with cell activity, oxidation-reduction conditions in the cell, and with iron supply. It was suspected that the active iron associated directly with chlorophyll was Fe^{2+}.

The direct reason for lime-induced chlorosis in the leaves of crops does not seem to be well defined. Some re - ports in the literature give actually contradicting conclusions. For example, while Gile and Carrero (1920) observed that a lack of iron in the plant is at least one of the causes of lime - induced chlorosis, later reports showed that there was no consistent correlation between total iron in the leaves of pear trees and lime-induced chlorosis (Lindner and Harley, 1944). These latter workers also found that lime-induced chlorosis was not correlated with insoluble Fe, nor with Fe soluble in water, ether, alcohol, 1N acetic acid, 1N ammonium hydroxide, or in 0.1N , or 1N HCl. However, iron extracted by 0.5N HCl was found to be lower in chlorotic leaves; HCl probably removed the Fe from an enzyme that plays a role in chlorophyll formation. Watanabe et al. (1965) concluded that Fe concentration per se was not the direct cause of the appearance of deficiency symptoms and reduced growth.

Plants which are sensitive to lime-induced chlorosis have been found to be more dependent on cytochrome as a terminal oxidase than are resistant plants (Wallace and Lunt , 1960) . Deckock (1971) reported that catalase activity was several fold greater in green than in chlorotic leaves. Fleming (1979) found that Fe stress in wheat was characterized by a decrease in the pH of the nutrient solution, leaf chlorosis, and increased reduction at the root surface.

The sap of chlorotic plants generally have a higher pH (up to one unit) and a greater reducing power than sap of green plants (Pouget and Justem 1965). Lindner and Harly (1944) and many other reported that iron chlorotic plants are generally characterized by deficient chlorophyll, high nonprotein nitrogen, high organic acids, an increased phosphoenol pyruvate carboxylase activity , low HCl-soluble iron, high K, low Ca and Mg, upset Mn/Fe ratio, and high citric acid.

Iron Application to the Soil

Iron deficiencies in plants are usually corrected by making the soil Fe more available or through the addition of Fe to soil or to plants in available forms . Increasing the availability of the native soil Fe is accomplished through proper soil management practices like moisture control, or acidifying alkaline soils by the application of ammonium sulfate or sulfur (FAO, 1972).

The addition of inorganic as well as organic compounds to the soil have been used to increase iron availability to plants. Olson (1951) used $FeSO_4$ as a soil amendment in a greenhouse study with grain sorghum. Applications equivalent to 1,120 kg $FeSO_4$/ ha increased Fe absorption. Mathers (1970) found that $FeSO_4$ and H_2SO_4 had similar effects in increasing the yield of hybrid grain-sorghum. The addition of 250 ppm of H_2SO_4 or Fe as $FeSO_4$ still had a significant effect on the third crop in the greenhouse. In the field, he found that 560 kg/ ha of H_2SO_4 or $FeSO_4$ produced about the same yield response on a calcareous soil. On the other hand, Follett and Lindsay (1971) found that only 20% of the Fe added as $FeSO_4 \cdot 7H_2O$ remained extractable after one week. Previous studies by the same authors had shown that most soil-applied inorganic Fe fertilizers were highly unavailable and provided little correction of Fe deficiency .

Barrau and Berg (1977) found that pyrite, pyrite mill tailing, and $Fe_2(SO_4)_3$ all supplied enough available Fe to a calcareous Fe-deficient soil to increase sudangrass yield by 160-200% over the control in a greenhouse experiment. Hodgson et al . (1972) applied 56-2,200 kg/ ha Fe as $Fe_2(SO_4)_3$ and grew four crops of corn over a period of 2 years in a calcareous soil in a greenhouse experiment. All levels of added Fe improved crop growth with the optimum response being at 186 µg/g and above .

Agricultural use of chelates has been influenced by the cost of the materials, their stability, pH of the soil, the kind of crop, and the competition between the chelating agent and the roots for the nutrient elements. The stability of a metal chelate usually increases with the charge of the metal ion; this is one reason why Fe^{3+} forms stable chelates than Fe^{2+} in most instances (Lehman, 1963) .

When growing wheat in solution and sand cultures, Zuev et al . (1961) found that Fe content in the leaves and roots of wheat receiving Fe-ethylenediaminetetraacetic acid (FeEDTA) chelate was higher than in those of plants receiving ionic Fe. Brown et al. (1961) grew eight plant species including wheat in nutrient solutions containing Fe as FeDTAP. Wheat growth was reduced sharply when the molar concentration of DTPA exceeded that of Fe.

The chelate FeEDDHA is stable in the alkaline range up to at least pH 10 with a stability constant of more than 10^{30} (depending upon the relative concentrations of Fe and the competing agents in solution). It has a very high affinity for Fe^{3+}, but has a weak binding of Zn^{2+} and Mn^{2+} and a very weak binding of Ca^{2+} and Mg^{2+}(Brown,1969). Halvorson and Lindsay (1972) found that when increasing the pH from 4 to 9, displacement of $Fe^{3+}$from the following chelating agents by divalent cations was in the order

EGTA# > EDTA > CDTA## > EDDHA.

In a greenhouse experiment, when FeEDDHA was applied to soil, the iron remained 80 to 67% extractable by DTPA during 6 weeks of oats cropping period. The added FeEDDHA

Ethyleneglycol - bis (2-amino-ethylether tetraacetic acid

Cyclohexanediaminetetraacetic acid.

was still 26% DTPA- extractable after 14 weeks. This reflects the ability of FeEDDHA chelate to maintain available Fe (Follett and Lindsay, 1971). Barrau and berg (1977) found that the addition of 5 ppm Fe as FeEDDHA for an Fe deficient calcareous soil increased the yield of sudangrass for two crops in a greenhouse experiment.

Jerzy and Amos (1976) compared the effectiveness of serveral sources of iron by growing beans in the greenhouse in two calcareous iron-deficient soils. The sources were $FeSO_4$, FeEDTA, FeEDDHA and Fe^{2+} bound to montmorillonite clay. They found that FeEDDHA interfered with plant development and suggested that iron attached to montmorillonite claly can be used as an efficient source of iron for plants grown in calcareous soils .

MATERIALS AND METHODS

Sampling and Soil Preparation

Bulk samples of surface soils (o to 25 cm) were collected from farmers' fields from three sites in the Jordan Valley. These samples were sampled within the Ghor 1 and the Zor soil series according to the 1969 classification by Dar Al-Handasah Consulting Engineers and the Netherlands Engineering Consultants. To facilitate discussion and for easy reference the three soils will be named by the location of the collected samples. The clay Zor soil will be referred to as Yabis, and the clay Ghor 1 soils will be referred to as Jerm and Krimeh . Locations of the sites are shown in Fig. 1

The bulk soil samples were air dried, crushed with a glass bottle, and passed through a 5-mm screen. Representative subsamples of 2 kg each were taken for soil characterization. The subsamples were ground and passed through a 2 - mm sieve. The samples for micronutrient determinations were ground to pass 0.85-mm sieve. Some important properties of the three soils are shown in Table 1.

The Greenhouse Experiment .

The design used in the experiment was a split-split-plot. Six levels of iron from two different source materials were applied to the three soil. Each treatment was

Fig.1. A map of Jordan and an enlargement showing the locations of the three soils used in the study.

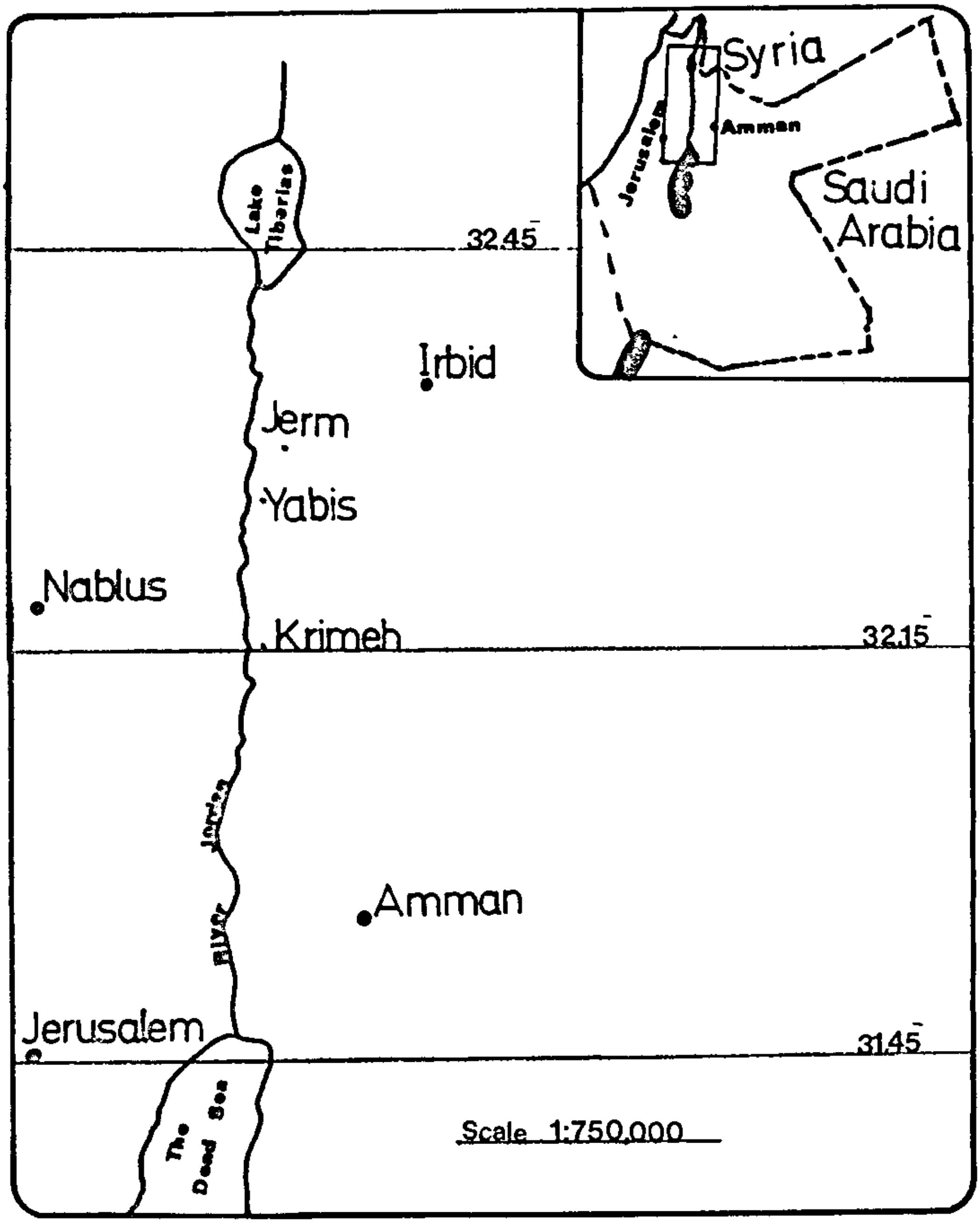

Table 1. Some chemical and Physical properties of the Jerm, Yabis, and Krimeh soils used in the study

Soil[#]	Total $CaCO_3$	Active $CaCO_3$	Total Fe_2O_3	Organic matter	Sand[##]	Silt	Clay	Extractable Fe	Extractable P	Extractable K	pH (1:1)	EC mmhos/cm	CEC meq/100g
	%							ppm					
Jerm	59.6	25.0	2.5	3.0	32.0	22.9	45.1	4.1	34	326	8.2	1.2	21.1
Yabis	43.4	16.6	4.3	3.2	23.6	28.9	47.5	6.0	49	888	8.0	1.9	27.4
Krimeh	25.5	9.1	5.2	1.4	27.4	24.1	48.5	5.3	119	665	7.9	3.4	33.5

[#] To facilitate discussion, soils were named by their location .

[##] Sand > 50 μm, silt 50–2 μm, and clay < 2 μm .

replicated four times to give a total of 132 pots. The two source materials of iron were the main plots in the design. The subplots were the three soils and the levels of applied iron were the sub-subplots.

Chelated iron, iron -ethylenediamine di (o-hydroxy phenyl acetate), (FeEDDHA), with 6% Fe, was applied at the rates of 0, 0.1, 0.5, 2.5, 5.0, and 10.0 ppm Fe. Iron sulfate ($FeSO_4 \cdot 7H2O$) was applied at the rates of 0, 10, 50, 100, 250, and 500 ppm Fe.

Two and a half kilograms of soil were taken for each pot. The fertilizer was mixed well with the soil as a solution. It was dissolved in enough water to wet the soil evenly without puddling. The wetted soil was put in a plastic bag overnight to equilibrate, then dried . This step was repeated once with distilled water. The polyethylene pots used were 20 cm in diameter and 20 cm in depth. On 7 Mar. 1979, 15 seeds of 'Stork' wheat (Triticum durum L.) were planted in each pot and were thinned to 10 plants per pot after one week. Pots were irrigated with distilled water as needed. Nitrogen was added to the soil twice as NH_4NO_3 solution; 50 ppm N was added after 2 days of planting and 25 ppm N after 4 weeks of planting. Phosphorus was added to the soil as KH_2PO_4 solution at the rate of 10 ppm after 4 weeks from planting. Plants were sprayed with Metasystox to control aphids. After 6 weeks from planting , when plants started blooming , tops were harvested about 1 cm above the surface of the soil, washed with detergent, rinsed thoroughly with distilled water, and then dried in an oven at 65°C. The dried plants were weighed and ground to pass a 40-mesh sieve. The soil in each pot was mixed well after removal of large roots and about a 70-g soil sample was taken.

On 29 Apr. 1979 pots were planted to a second crop of wheat. Nitrogen was added at the rate of 50 ppm N and phosphorus at the rate of 10 ppm. On 11 June 1979 plants were harvested. Plants and soil were handled in the same manner as in the first crop .

Soil Analysis

Extractable Fe, Mn, Cu, Zn, and P were determined in the soil samples after the harvest of each crop.

Plant Analysis

The wet digestion method was used and total Fe, Mn, Zn, P and Ca were determined in plants for the two crops.

Analytical Procedures

The analytical procedures which were used were as follows; $CaCO_3$ was determined by the pressure calcimeter method (Allison and Moodie, 1965). Total iron by decomposition with HF (Olsen, 1965) . Extractable Fe, Mn, Zn, and Cu by using DTPA as an extractant (Lindsay and Norvell, 1978). Extractable phosphorus with sodium bicarbonate (Watanabe and Olsen, 1965). Extractable potassium with ammonium acetate (Pratt, 1965). Organic matter by Walkley-Black method (Allison, 1965). Cation exchange capacity by sodium acetate saturation (Chapman, 1965). Particle-size distribution by the hydrometer method. Wet digestion of plant (Johnson and Ulrich, 1959). Amounts of Fe, Mn, Zn and Cu in solutions were determined by atomic absorption spectroscopy. Total phosphorus in plant was determined by the vanadate method (Jackson, 1958) and total Ca in plant by back titration with EDTA and $CaCl_2$ (Heald, 1965).

RESULTS AND DISSCUSION

The three soils in the study were highly calcareous with $CaCO_3$ content ranging from 25 to about 60% . The active[#] $CaCO_3$ in the three soils was 9.1 % in Krimeh, 16.6% in Yabis, and 25.0% in Jerm (Table 1). The effect of iron fertilizers added to these soils on soil DTPA-extractable iron, plant yield, and Fe content in the plant was investigated.

Soil Extractable Iron

The DTPA extractable iron in the three soils treated with different levels of iron chelate or iron sulfate was determined after each of the two crops. Results are shown in Fig 2.

After the first crop the iron extracted from Krimeh and Yabis soils treated with 10 ppm chelated iron was equivalent to that extracted from the same soils when treated with 250 ppm Fe as $FeSO_4$.

Among the three soils, Yabis had the highest extractable iron with all levels of added chelated Fe. At the higher levels of $FeSO_4$ (100,250 and 500 ppm Fe) Jerm had higher

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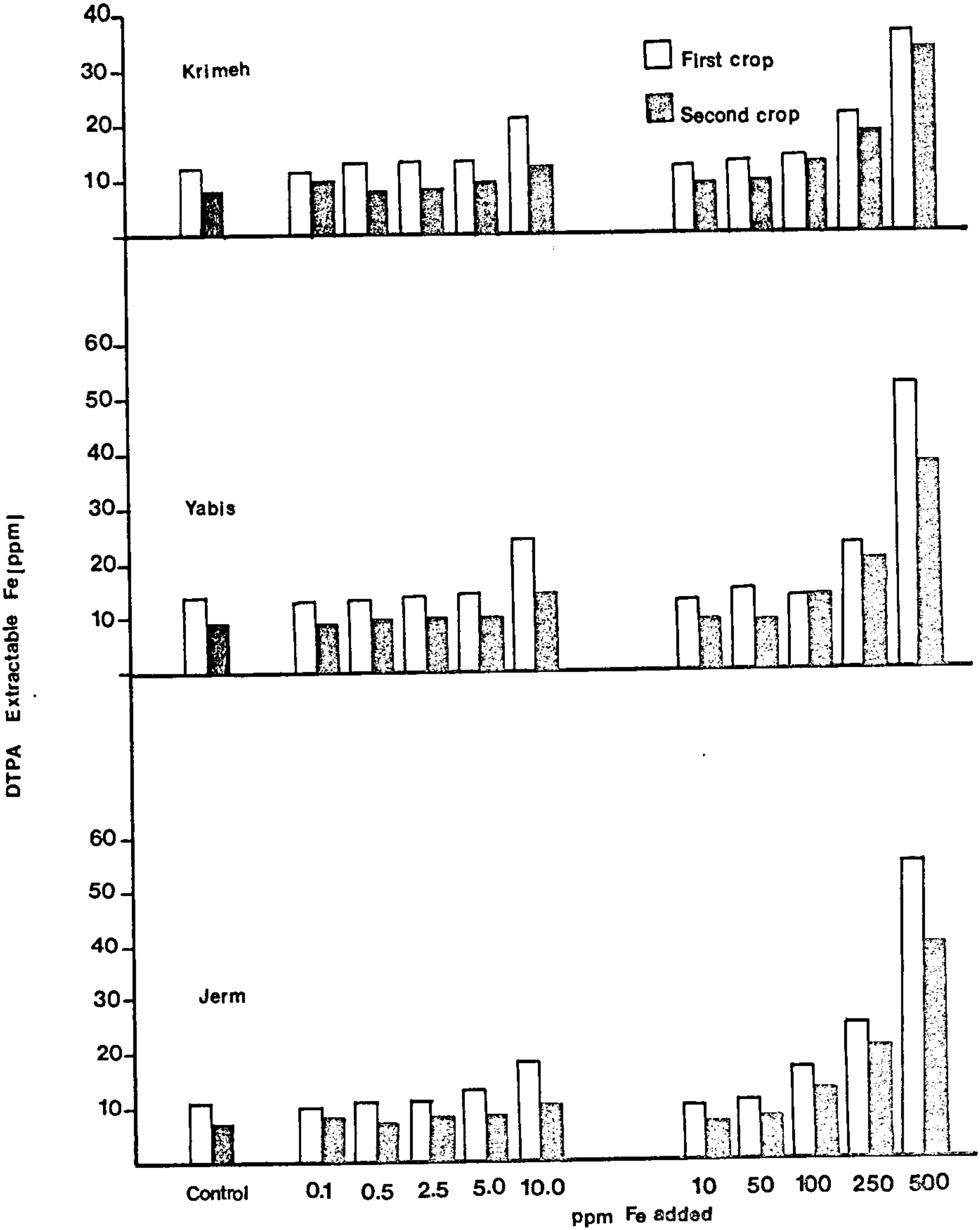
[#] Drouineau, G., 1942 . Dosage rapide du Calcaire actif du 80 1. Nouvelles donnees surle repartition et la nature des fractions calcaires - Annales Agronomiques . 12:A41-450

Fig.2. DTPA extractable iron in Jerm,Yabis, and Krimeh soils after each of the two crops of wheat.



values of extractable iron than Yabis and Krimeh .

The DTPA extractable iron decreased after the second crop, but it still showed trends similar to those of the first crop. Yabis had the highest extractable iron from almost all the chelated-iron treatments; for the added inorganic iron, Jerm had more extratable iron from the higher treatments.

Extractable iron in the controls increased after the first crop and decreased after the second crop, but remained higher than it was before cropping (Table 2). Similar trends were observed by many investigators . Follet and Lindsay(1971) found that after planting oats and corn, extracttable iron increased in most soils they used. Elliott and Blaylock (1975) found that wheat straw added to the soil increased DTPA-extractable iron. They suggested that this may be related either to the activity of microorganisms or root decomposition in the soil. In the present study the increase may be related to the ability of DTPA to extract Fe from the root residues. In a pot experiment where wheat was added with and without 200 ppm Fe as $FeSO_4$ in different combinations.Courpron and Juste (1975) found that the antichlorotic effect of $FeSO_4$ was greatly increased with the incorporation of plant residues. In the present investigation plant residues in Jerm soil were more than in Yabis and Krimeh soils, and the increase in extractable iron from the controls was relatively higher for the Jerm soil than for the other two soils. This could also explain the fact

Table 2 . Extractable iron before and after each of the two crops of wheat from Jerm , Yabis,and Krimeh soils

Soil	DTPA- extractable Fe		
	Before planting	After first crop	After second crop
	ppm		
Jerm	4.1	10.7	7.4
Yabis	6.0	13.6	9.0
Krimeh	5.3	12.3	7.9

that extractable iron for the high applications of $FeSO_4$ was more for Jerm than for Yabis and Krimeh ((Fig.2) .

The results of the present study indicate that the indigenous DTPA extractable iron of 4.1-6.0 ppm (Table 1) was adequate for two crops of wheat grown in these highly calcareous soils and iron availability was not the limiting factor for plant growth .

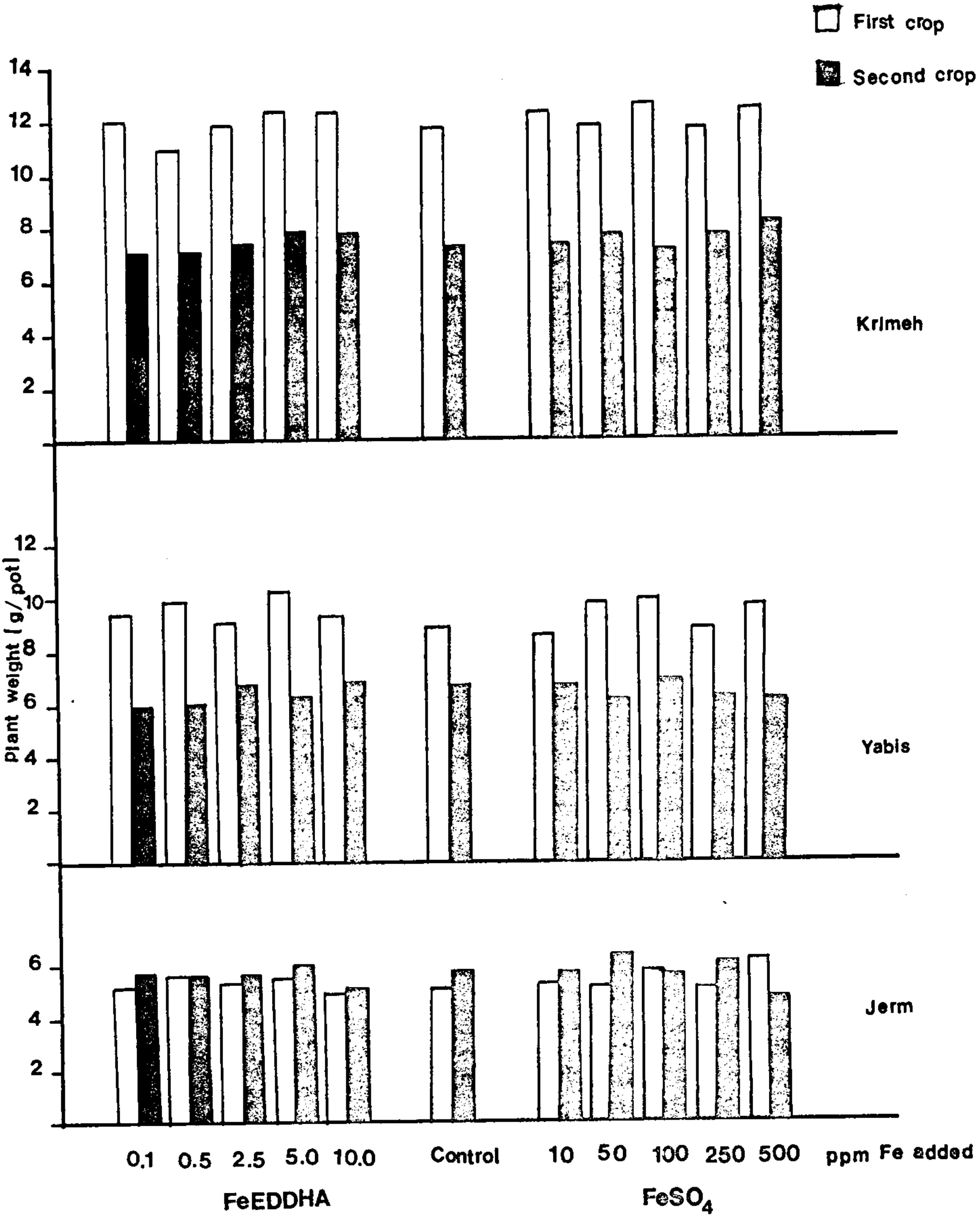
Plant Yield

Dry matter yield of wheat for the two crops is shown in Fig. 3. Statistical analysis of the data showed that there were significant differences among yields of the different soils. In the first crop highest yields were for Krimeh soil followed by Yabis and then Jerm. For the same soil there was no clear relationship between yield and the source or amount of iron added to the soil.

The highest yield in Jerm was from the treatment of 500 ppm Fe as $FeSO_4$ which was 22% over the control. In Yabis, the highest yield was from the 5 ppm chelate iron treatment (16 % over the control). The highest increase of yield in Krimeh was from the addition of 100 ppm Fe as $FeSO_4$ (8% over the control).

The same trends were observed in the second crop . Generally, Krimeh had the highest yields and Jerm the lowest. Differences among the yields of the three soils were smaller in the second crop. This is due to the noticeable decrease in the yields of Yabis and Krimeh while the yields of

Fig.3. Dry matter yield per pot for the two crops of wheat grown in Jerm, Yabis, and Krimeh soils.



Jerm stayed about the same as in the first crop or increased in some cases. The treatment of 500 ppm Fe as $FeSO_4$ gave the lowest yield in Jerm which was 19% lower than the control. The same treatment decreased the yield by 19% in Yabis although it increased the yield in Krimeh by 11% over the control. These results again emphasize the lack of any consistent relationship between added iron and the dry matter yield.

The yield of the two crops of wheat in the three soils could be more related to the $CaCO_3$ content of the soil than to the level of iron in the soil. The average dry matter yield of the two crops of wheat decreased with the increase of total or active $CaCO_3$ in the soil .

Iron Concentration in Plant

The Fe concentration in the two crops of wheat is shown in Table 3. In the iron chelate treatments, first crop of wheat grown in Jerm and Yabis had the highest iron concentration with the addition of 10 ppm Fe while in Krimeh highest concentration was with the addition of 2.5 ppm Fe. Most other iron chelate treatments had higher or around the concentration in the control. Iron concentration in wheat grown in soils receiving $FeSO_4$ generally decreased compared to the non-treated soils. Increasing the level of applied $FeSO_4$ seemed to decrease the concentration of iron in the plant.

Table 3. Iron concentration in the above ground part of the two crops of wheat grown in Jerm, Yabis, and Krimeh soils

Soil	Control	FeEDDHA ppm					FeSO$_4$ ppm				
		0.1	0.5	2.5	5.0	10.0	10	50	100	250	500
	ppm										
First crop											
Jerm	33.2	36.5	34.2	35.5	31.8	42.0	32.2	30.3	29.7	29.9	27.3
Yabis	35.7	38.2	36.4	38.4	39.2	40.8	37.0	30.1	31.9	27.1	27.3
Krimeh	42.3	43.2	39.2	48.8	41.4	44.3	35.7	35.0	33.9	32.7	31.8
Second crop											
Jerm	41.7	40.3	48.7	39.8	39.3	45.5	40.4	42.0	40.5	35.7	38.3
Yabis	46.0	45.6	41.6	35.3	43.3	39.2	43.3	41.7	40.8	37.8	45.5
Krimeh	44.7	53.5	44.0	45.0	43.2	45.8	48.7	45.8	46.3	37.5	41.0

In the second crop of wheat iron concentration increased for all treatments of both Fe sources in Jerm relative to the first crop. For Yabis and Krimeh soils the concentration increased for all inorganic and most of the organic treatments.

In the first crop the concentration of Fe in the plant decreased while the DTPA-extractable Fe increased with the increase of applied $FeSO_4$ (Fig. 2 and Table 3). This indicates that $FeSO_4$ is not an effective source of iron when applied to a calcareous soil even when part of it is still extractable. Probably wheat plants prefer to absorb iron when present in soil in anionic forms. Wallace and Shannon (1956)# reported that 24% of the iron removed by plants from a calcareous soil was in the anion form. As shown in table 4, it seems that for the three soils when treatments from the organic and the inorganic sources had nearly the same extractable iron, the concentration in wheat was higher for the organic treatments than for the inorganic ones. The contradicting results of high extractable iron in soil with the high application rates of $FeSO_4$ and the low iron concentration in plant at these rates could be explained as an iron toxicity rather than deficiency. This is exhibited in the low values of total manganese in plant. This was most obvious at the 500 ppm treatments in the first crop where plants contained 30,60 and 60% of total Mn in the control in Jerm, Yabis,and Krimeh soils respectively. In the second crop and for the same treatments the values were 30, 40, and 50% of Mn

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From Wallace (1963).

Table 4. Iron concentration in plant and plant uptake in the first crop of wheat as related to extractable Fe from soils treated with chelated or inorganic source of iron

Soil	Organic source #			Inorganic source##		
	Extractable	Concentration in plant	Plant uptake	Extractable	concentration in plant	Plant uptake
	ppm		µg/pot	ppm		µg/pot
Jerm	11.4	35.4	188	11.3	30.3	158
Yabis	14.2	38.4	348	14.6	30.1	295
Krimeh	13.1	48.8	580	12.8	35.0	410

\# 2.5 ppm Fe as FeEDDHA

\## 50 ppm Fe as $FeSO_4$

in the control (Table 5). #Mass (1967) found that Fe^{2+} reduced Mn absorption by barley roots, but Fe^{3+} did not . Somers and Shive (1942) cited that symptoms of iron toxicity corresponded to those of Mn deficiency. Olomu et al. (1973) found that the majority of Fe in soil extracts (soils with pH around 7.5) was present as a negatively charged complex and was related to the organic matter content of the soil; they also noted that plant nutrition was affected by the natural chelating agents present in the soil. In the present study, the high amounts of extractable iron from soils treated with $FeSO_4$ and the low iron concentration in wheat grown on these soils might be due to the presence of Fe in a cationic form for the growing period of the plants.

Iron Uptake from Soil

Iron uptake was calculated as µg Fe per pot and is presented in Fig 4. In the first crop the addition of chelated iron generally led to an increase in the uptake of iron while the addition of inorganic iron decreased iron uptake compared to the control .

The uptake of iron in the second crop increased for wheat grown in Jerm while it decreased for the other two soils compared to the first crop. These differences in the

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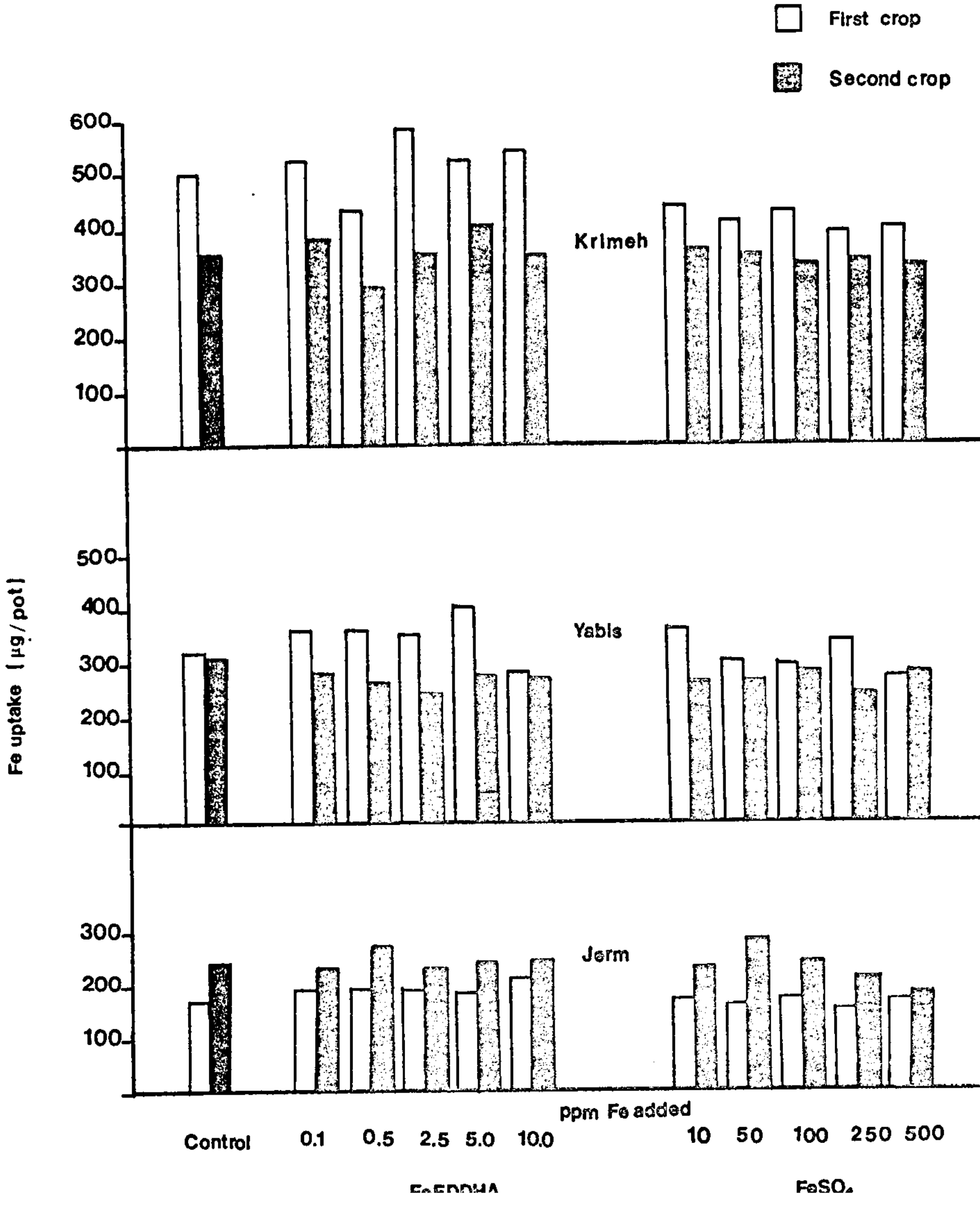
From Moore 1972 .

Table 5. Manganese concentration in the two crops of wheat grown in the Jerm, Yabis, and Krimeh soils

Soil	Control	FeEDDHA					FeSO4				
		ppm									
		0.1	0.5	2.5	5.0	10.0	10	50	100	250	500
	ppm										
	First crop										
Jerm	44.3	43.5	46.5	35.7	27.3	19.5	37.9	30.8	23.8	21.5	14.3
Yabis	39.9	42.1	40.2	39.3	37.3	33.8	33.7	30.2	26.3	26.0	23.5
Krimeh	60.6	55.7	55.5	51.5	49.9	54.0	49.6	40.7	38.8	41.8	35.8
	Second crop										
Jerm	50.5	51.0	46.3	27.9	24.7	15.3	41.8	37.2	21.8	15.0	13.8
Yabis	41.3	34.4	34.5	29.3	25.5	22.5	31.9	25.8	25.5	22.3	16.9
Krimeh	55.2	57.8	50.2	44.7	47.8	42.9	51.4	40.9	46.4	30.4	29.3

Fig.4. Iron uptake by the two crops of wheat from the Jerm, Yabis, and Krimeh soils.



uptake among soils reflect the differences in the yield and iron concentration in plant between the two crops. The yield and iron concentration increased in Jerm while the decrease in yield in the other two soils was enough to result in lower uptake (Figs. 2 and 4 and Table 3) .

Iron uptake seemed to be related to the $CaCO_3$ content in the soils; Jerm had the highest $CaCO_3$ content and the lowest iron uptake while Krimeh had the lowest $CaCO_3$ content and the highest Fe uptake. This inverse relationship was observed in the two crops of wheat .

Phosphorus in Soil and Plant

a- In soil

After the first crop, extractable P decreased compared to the initial value and nearly leveled until after the second crop (Tables 1 and 6). The decrease in extractable phosphorus was more in soils that had the greatest dry matter yield; hence the decrease in extractable phosphorus was the greatest in Krimeh (Fig. 3 and Table 7) .

b- In plant

In the first crop, symptoms of P deficiency appeared on wheat grown in Jerm and phosphorus was added (10ppm P as KH_2PO_4) for all treatments in the three soils. One can conclude that for highly calcareous soils 34 ppm $NaHCO_3$-extractable P was not sufficient for wheat and 120 ppm or lower extractable P did not affect iron availability.

Table 6. Soil extractable phosphorus for the three soils after each of the two crops of wheat

Soil	Control	FeEDDHA ppm					FeSO4				
		0.1	0.5	2.5	5.0	10.0	10	50	100	250	500
	ppm										
						First crop					
Jerm	26.8	26.5	28.0	26.0	25.8	28.3	23.5	25.5	25.0	25.5	28.5
Yabis	26.0	27.5	26.7	30.0	25.8	26.8	26.0	26.8	32.0	30.0	27.8
Krimeh	75.5	74.0	78.0	80.5	73.5	80.0	71.0	76.5	77.0	71.0	71.5
						Second crop					
Jerm	26.3	28.5	24.3	26.5	30.0	29.3	32.0	24.8	24.8	22.5	23.3
Yabis	27.8	29.0	26.3	27.0	25.5	28.5	29.5	23.0	22.5	24.0	23.0
Krimeh	68.5	74.0	68.5	76.5	70.0	77.0	74.0	63.0	72.5	62.3	69.5

Table 7. Extractable phosphorus before and after planting of the two crops in the Jerm, Yabis, and Krimeh soils

Soil	Before planting	Control	Treatments #	Control	Treatment
			ppm		
Jerm	34.1	26.0	26.3	26.6	26.6
Yabis	48.7	26.o	28.0	26.8	25.9
Krimeh	119.3	75.5	76.0	68.5	70.6

Average of all treatmemt .

Table 8. Phosphorus content in the two crops of wheat grown in Jerm, Yabis and Krimeh soils

Soil		FeEDDHA					FeSO$_4$				
	Control	0.1	0.5	2.5	5.0	10.0	10	50	100	250	500
	%										
					First crop						
Jerm	0.23	0.22	0.19	0.24	0.18	0.19	0.20	0.21	0.25	0.24	0.23
Yabis	0.21	0.20	0.21	0.21	0.22	0.22	0.22	0.23	0.21	0.21	0.23
Krimeh	0.36	0.33	0.33	0.33	0.34	0.34	0.33	0.34	0.32	0.32	0.29
					Second crop						
Jerm	0.26	0.28	0.26	0.30	0.22	0.29	0.24	0.20	0.23	0.26	0.31
Yabis	0.30	0.31	0.31	0.32	0.33	0.28	0.22	0.24	0.24	0.33	0.37
Krimeh	0.37	0.36	0.34	0.38	0.38	0.37	0.33	0.33	0.32	0.37	0.32

Phosphorus concentration in plant is presented in table 8 . It seemed that for most treatments it was higher in Krimeh than in Yabis and Jerm for the two Crops of Wheat The inverse relationship between the $CaCO_3$ in the soil and the P content in the plant is implied in these results .

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted to study the response of wheat to Iron fertilization in calcareous soils from the Jordan Valley.Three soils were used. Yabis soil was chosen from the Zor series,Krimeh and Jerm were chosen from Ghor 1 series. The calcium carbonate content in Krimeh, Yabis, and Jerm soils was 26, 43, and 60% respectively .

The experiment was set up using a split-split-plot design. Two sources of iron were used. Iron chelate (FeEDDHA) at rates of 0, 0.1, 0.5, 2.5, 5.0, and 10.0 ppm Fe and $FeSO_4$ at rates of 0, 10, 50, 100, 250, and 500 ppm Fe. Each treatment was replicated four times. Two crops of wheat were grown for six weeks each.

Wheat growth, iron concentration in the plant, and iron uptake were mainly related to the $CaCO_3$ content in the soil. Addition of iron chelate did not increase plant growth, but generally increased iron concentration in the plant.

The application of $FeSO_4$ to these highly calcareous soils had a toxic effect on wheat which was displayed in low concentrations of Fe and Mn in the plant esperialy in Jerm soil.

Extractable Fe increased after planting in the control treatments. This could be due to the ability of DTPA to extract Fe from the root residues. Extractable Fe of 4.1-6.0 ppm seemed to be sufficient for wheat growth in the soils used in the present study .

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Table I

DTPA extractable Mn in the Jerm, Yabis, and Krimeh soils after each of the two crops of wheat

		FeEDDHA						FeSO$_4$				
Soil	Control	0.1	0.5	2.5	5.0	10.0	ppm	10	50	100	250	500
							ppm					
							First crop					
Jerm	13.0	14.3	14.4	11.4	15.9	15.9		10.0	14.6	14.1	13.7	13.5
Yabis	16.5	20.7	18.9	20.4	21.5	20.0		16.1	18.8	17.9	17.2	20.2
Krimeh	14.7	21.2	19.3	18.7	24.1	18.3		19.6	19.6	19.3	19.0	19.1
							Second crop					
Jerm	11.3	13.0	10.6	13.2	9.2	12.0		13.5	19.1	14.0	10.6	15.2
Yabis	15.5	18.2	13.9	19.2	12.7	19.6		15.6	26.2	16.8	13.6	21.8
Krimeh	11.0	16.0	13.5	19.8	12.8	16.2		15.9	24.1	15.0	11.3	19.0

Table II

Zinc concentration in the above ground part of the two crops of wheat grown in Jerm, Yabis, and Krimeh soils .

		FeEDDHA					FeSO$_4$				
		ppm					ppm				
Soil	Control	0.1	0.5	2.5	5.0	10.0	10	50	100	250	500
	ppm										
	First crop										
Jerm	46.5	37.8	38.9	32.0	23.8	19.4	33.3	33.0	27.2	23.5	23.5
Yabis	34.4	29.9	27.4	28.2	24.5	22.5	27.5	24.5	24.8	18.7	18.8
Krimeh	41.7	35.0	31.8	33.8	28.4	24.8	31.2	29.5	26.8	21.4	20.9
	Second crop										
Jerm	27.3	34.0	30.7	21.7	20.3	20.5	26.2	28.0	24.5	18.3	22.0
Yabis	23.3	22.3	22.9	18.5	16.5	15.5	21.0	19.3	20.0	22.7	22.0
Krimeh	30.5	36.8	27.5	25.5	23.2	21.2	27.8	26.5	27.5	20.2	19.2

Table III

Extractable zinc in the Jerm, Yabis, and Krimeh soils after each of the two crops of wheat

Soil	Control	FeEDDHA					ppm	$FeSO_4$				
		0.1	0.5	2.5	5.0	10.0		10	50	100	250	500
							ppm					
							First crop					
Jerm	2.0	2.4	2.6	2.2	2.3	2.5		2.1	2.7	2.3	2.4	2.2
Yabis	2.1	2.9	3.1	2.5	2.4	2.5		2.1	2.4	2.6	2.6	2.1
Krimeh	2.8	3.9	3.3	3.1	3.3	3.2		3.1	3.4	3.8	3.6	2.7
							Second crop					
Jerm	1.7	1.9	1.9	1.7	1.7	2.0		1.8	2.4	2.4	1.8	1.7
Yabis	1.9	1.4	1.9	1.9	1.7	2.1		1.8	2.5	2.1	1.9	1.7
Krimeh	2.3	2.3	2.7	2.8	2.6	2.8		3.2	2.6	2.8	2.4	2.4

Table IV

Copper concentration in the above ground part of the crops of wheat grown in Jerm, Yabis, and Krimeh soils .

		FeEDDHA						FeSO$_4$				
							ppm					
Soil	Control	0.1	0.5	2.5	5.0	10.0		10	50	100	250	500
							ppm					
							First crop					
Jerm	8.4	7.4	8.0	7.4	5.7	5.2		8.4	7.8	7.0	6.8	6.0
Yabis	7.6	6.8	6.9	6.8	6.1	5.7		6.8	6.5	5.8	5.7	4.9
Krimeh	8.3	7.8	8.0	6.4	8.9	9.4		7.9	7.2	6.0	6.3	6.3
							Second crop					
Jerm	7.9	8.5	8.3	8.8	6.7	6.2		7.6	7.5	6.4	6.0	5.4
Yabis	7.1	7.0	6.3	6.4	5.4	5.5		6.9	6.9	5.8	5.6	4.8
Krimeh	8.2	7.4	7.2	7.7	7.4	9.3		7.5	7.1	6.0	5.9	4.6

Table V

Extractable copper in the Jerm, Yabis, and Krimeh soils after each of the two crops of wheat

Soil	Control	FeEDDHA					ppm	$FeSO_4$				
		0.1	0.5	2.5	5.0	10.0		10	50	100	250	500
							ppm					
							<u>First crop</u>					
Jerm	2.1	2.5	2.7	2.5	2.2	2.5		2.0	2.8	2.7	2.8	2.8
Yabis	2.0	2.8	3.1	2.8	2.6	2.5		1.9	2.8	2.9	2.9	2.8
Krimeh	1.8	2.8	2.6	2.3	2.2	1.9		2.0	2.4	3.3	3.2	2.6
							<u>Second crop</u>					
Jerm	2.4	2.9	2.6	2.6	2.1	2.1		2.2	2.2	2.4	2.4	2.6
Yabis	2.4	2.5	2.8	2.8	2.2	2.4		2.1	3.1	2.5	2.5	2.6
Krimeh	2.1	2.5	2.6	2.7	2.3	2.2		2.3	2.5	2.6	2.2	2.5

Table VI

Calcium Concentration in the above ground part of the two crops of wheat grown in Jerm, Yabis, and Krimeh soils.

	FeEDDHA							$FeSO_4$				
	Control	0.1	0.5	2.5	5.0	10.0		10	50	100	250	500
							%					
							First Crop					
Jerm	0.35	0.42	0.31	0.31	0.26	0.31		0.34	0.32	0.37	0.42	0.31
Yabis	0.26	0.34	0.24	0.32	0.26	0.33		0.29	0.29	0.40	0.40	0.31
Krimeh	0.41	0.46	0.33	0.46	0.40	0.50		0.38	0.42	0.44	0.45	0.50
							Second Crop					
Jerm	0.26	0.27	0.28	0.22	0.23	0.27		0.29	0.20	0.33	0.26	0.38
Yabis	0.26	0.25	0.27	0.22	0.18	0.17		0.22	0.21	0.32	0.32	0.30
Krimeh	0.42	0.40	0.46	0.36	0.38	0.34		0.38	0.39	0.44	0.41	0.46

ملخص

تشكل الترب‍ه الجيريه حوالي ثلث الاراضي الزراعيه في العالم و تتميز الترب‍ه الاردنيه بارتفاع النسبه المئويه للجير وخصوصا في وادي الاردن حيث لا تقل عن 20% في الطبقه السطحيه من التربه في اغلب الاحيان . وللجير تأثير على قابلية امتصاص العناصر المعدنيه من التربه وخصوصا الحديد . وتلاحظ أعراض نقص الحديد على النباتات الناميه في الاغوار وخصوصا اشجار الحمضيات لذا فمن الضروري دراسة حالة هذا العنصر الهام في تلك الاراضي.وكنقطه انطلاق فقد أجريت دراسه على ثلاثة انواع من الاتربه من وادي الاردن ، جمعت من مناطق الجرم واليابس والكريمه حيث تبلغ نسبة كربونات الكالسيوم في الطبقه السطحيه لهذه الاتربه هي 59 ,44 ,25 % على التوالي. لقد استعملت ستة مستويات من كل من الماده المخلبيه المحتويه على الحديد (FeEDDHA) وكبريتات الحديدوز ($FeSO_4$) وزرع محصولان متتابعان من القمح في بيت محمي ، وتم قص المجموع الخضري بعد ستة اسابيع من الزراعه في كل مره ، وقدر الحديد الكلي في النبات وكذلك الحديد المستخلص من التربه بعد كل زراعه. وتشير نتائج الدراسه الى ما يلي :-

ان الوزن الجاف للنبات وكذلك كمية الحديد الممتص من التربه يتأثران تأثيرا كبيرا بكمية كربونات الكالسيوم في التربه . فوزن النبات يزداد بانخفاض نسبة كربونات الكالسيوم في التربه وتأثير التسميد بالحديد على المحصول غير واضح مما يدل على أن قيمة مقدارها 6.0-4.1 جزء في المليون من الحديد المستخلص بواسطة (DTPA) والموجوده اصلا كانت كافيه لنمو القمح في الاتربه المستعمله في هذه الدراسه .

ازداد الحديد المستخلص من التربه بعد المحصول الاول والثاني بازدياد الحديد المضاف ولكنه انخفض بعد المحصول الثاني عما كان عليه بعد المحصول الاول وقد لوحظ أن الحديد المستخلص من (الشاهد) قد ازداد بعد الزراعه الاولى وبقي أعلى في الزراعه الثانيه عما كان عليه قبل الزراعه ، ويعزى ذلك الى بقايا المحصول السابق وقدرة الـ (DTPA) على استخلاص كمية من الحديد من بقايا الجذور .

أما تركيز الحديد في النبات فقد تبين أنه بوجه عام ينخفض بازدياد كمية كربونات الكالسيوم في التربه حيث كان اقل تركيزا في النباتات المزروعه في الجرم واعلى تركيزا في النباتات المزروعه في الكريمه . وقد ازداد تركيز الحديد باستعمال الماده المخلبيه في اغلب المعاملات وانخفض باستعمال كبريتات الحديد (ما عدا المستوى الاول في تربة اليابس) وقد ازداد الانخفاض بازدياد الحديد المضاف على صورة كبريتات حديدوز بالرغم من ازدياد الحديد المستخلص من التربه مما يدل على أن نبات القمح يفضل امتصاص الحديد من الاراضي الجيريه عندما يوجد في صوره عضويه كما تبين ان لكبريتات الحديد تأثير على امتصاص العناصر الاخرى وهذا واضح من انخفاض تركيز المنجنيز في النباتات المزروعه في التربه التي أضيف لها كميات كبيره من كبريتات الحديدوز .

انخفض الفسفور الميسر في جميع المعاملات بعد الزراعه الاولى بما فيها تلك التي لم يضف لها الحديد ، وقلّ ذلك بعد الزراعه الثانيه . وقد يرجع الانخفاض الى الكميه التي امتصها النبات حيث ان اعلى محصول كان في الكريمه ورافق اكبر انخفاض في تركيز الفسفور الميسر اما الفسفور الممتص فقد ازداد بانخفاض نسبة كربونات الكالسيوم بوجه عام وقد ظهرت اعراض نقص الفسفور على النباتات المزروعه في تربة الجرم في المحصول الاول ، لذا أضيفت عشرة أجزاء في المليون من الفسفور في صورة (KH_2PO_4) لجميع المعاملات في كل الاتربه . ومن هذا يمكن القول ان 34 جزءا في المليون من الفسفور الميسر في تربة تحتوى على 59% من كربونات الكالسيوم غير كافيه لنمو نبات القمح . كما ان 120جزءا بالمليون من فسفور لم توءثر على امتصاص الحديد من الاراضي الجيريه التي تحتوى على 25% من كربونات كالسيوم في هذه الدراسه .